International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347 -6435 (Online)), Volume 15, Issue 11, November 2026)

Integrating HACCP Requirements into Food Processing Plant Projects Through Design Reviews and Contractor Quality Assurance

Page Janet[1]

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***Abstract*—** Food safety remains a critical priority in modern food processing industries, where increasing production complexity, regulatory requirements, and contamination risks demand systematic preventive controls. The Hazard Analysis and Critical Control Points (HACCP) framework provides a structured approach to identifying, evaluating, and controlling biological, chemical, and physical hazards throughout food production. However, integrating HACCP requirements into food processing plant development presents challenges involving engineering design, equipment selection, construction quality, contractor coordination, and operational readiness. This study proposes an integrated project management framework incorporating HACCP principles into engineering design reviews and contractor quality assurance throughout the plant development lifecycle. The framework examines hygienic facility layouts, contamination prevention, material specifications, equipment installation, inspection procedures, and commissioning verification. It further establishes performance indicators for design compliance, contractor quality, corrective action closure, construction defects, and food safety readiness. A comparative evaluation approach is proposed to assess relationships between early hazard identification, design modifications, contractor performance, and commissioning outcomes. The framework supports proactive risk management, regulatory compliance, reduced construction rework, and improved operational preparedness, providing practical guidance for delivering food processing facilities with embedded preventive food safety controls.

***Keywords*—** Hazard Analysis and Critical Control Points (HACCP); Food Processing Plant Design; Design Reviews; Contractor Quality Assurance; Hygienic Engineering; Food Safety Compliance

I. INTRODUCTION

A. Food Safety and the Engineering Complexity of Processing Facilities

Food processing infrastructure supports public health protection, food security, product integrity and dependable industrial output. Contemporary facilities combine production machinery, utilities, building services, sanitation systems and controlled environments whose interfaces influence contamination control [1]. Poor layouts can bring raw materials into contact with finished products, while inadequate drainage, unsuitable surfaces and uncontrolled personnel movement create additional pathways [2]. These risks cannot always be corrected through operational procedures alone. Equipment accessibility, separation and service capacity require attention before construction fixes their physical arrangement. Considering food safety during project development therefore supports prevention rather than expensive adaptation after startup. Hazard Analysis and Critical Control Point systems provide a structured management approach, but their effectiveness depends partly on the infrastructure supporting implementation [3].

B. HACCP Requirements and Their Implications for Construction Projects

HACCP comprises hazard analysis, identification of critical control points, validated critical limits, monitoring, corrective action, verification and documentation [4]. An operational plan specifies controls for particular products and processes; construction projects establish conditions that enable those controls to function. Hygienic zoning, cleanable surfaces, accessible equipment, suitable utilities and contamination barriers commonly support prerequisite programmes rather than automatically constituting critical control points [5]. The engineering challenge is translating expectations such as effective cleaning or segregation into measurable requirements. Specifications need defined materials, layouts, access provisions and acceptance evidence, with criteria justified by the process and applicable requirements [1]. Early collaboration connects food safety expertise with engineering feasibility, procurement and installation. Consultants, contractors and operators consequently need shared understanding before approval, because compliance with a drawing cannot compensate for an inadequate specification.

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C. Fragmentation Between Design Reviews and Contractor Quality Assurance

Project delivery can separate design verification, food safety assessment, procurement and site inspection into distinct approval processes. This fragmentation creates a risk that each party verifies its own deliverable without checking whether the completed facility supports hygienic operation. A design review may confirm functionality and building requirements while overlooking cleaning access or contamination routes [6]. Contractor inspection can likewise establish conformity with approved drawings without establishing that their hygiene requirements are adequate. Potential consequences include unsuitable finishes, inaccessible equipment, drainage defects and unprotected service penetrations [7]. Discovery during commissioning can require costly modification and delay operational readiness. The proposed response is a traceable process linking hazard-informed requirements, design decisions, purchased components and construction evidence. Approval therefore addresses both specification adequacy and installation conformity, with unresolved concerns assigned to accountable owners.

D. Research Aim, Objectives and Article Contribution

This article develops an integrated framework for embedding HACCP-related requirements within design reviews and contractor quality assurance throughout food processing plant projects. Its objectives cover hazard-informed requirement identification, multidisciplinary design verification, contractor inspection planning, construction evidence management and commissioning readiness. The contribution is a practical connection between food safety risk management and engineering project quality systems, rather than a claim that construction controls independently guarantee safe production. The framework supports operational HACCP development, validation and verification without replacing them [8]. The article progresses through technical foundations, methodology, implementation and evaluation. Having established the delivery disconnect, the next section defines engineering requirements and the evidence needed to translate them into design and construction verification activities before acceptance and operational handover decisions.

II. HACCP REQUIREMENTS AND FOOD PROCESSING PLANT ENGINEERING

A. HACCP Principles and Their Relationship to Facility Design

HACCP comprises hazard analysis, identification of critical control points, establishment of validated critical limits, monitoring, corrective action, verification and documentation [4]. These principles operate within a food safety system supported by prerequisite programmes, including hygiene, maintenance and pest control [5]. Hazard-specific operational measures differ from foundational provisions such as cleanable rooms or segregated access [4]. Processing environments can introduce biological contamination, cleaning chemicals, foreign materials and allergen cross-contact [5]. Infrastructure influences their introduction, persistence and transfer through surfaces, airflow, water, equipment and movement routes [6].

Design supports control by providing accessible monitoring locations, cleanable assemblies, separation and maintainable equipment [7]. Corrective action also depends on practical arrangements for isolation, drainage and safe intervention. However, construction inspection establishes only whether specified provisions exist and conform to acceptance requirements. It does not identify every operational critical control point, establish process-specific critical limits or validate the HACCP plan [8]. Those responsibilities require operational evidence and competent assessment.

B. Hygienic Zoning, Layout and Contamination Control

Zoning separates raw materials, intermediate products, finished goods and waste according to process-specific contamination risks [6]. High-care designations require an explicit rationale rather than a generic label. Personnel routes, changing facilities, handwashing stations and controlled entry must support the intended separation [5]. Equipment placement considers product travel, cleaning access and maintenance movement, reducing unnecessary crossings and inaccessible spaces [7].

Ventilation and pressure relationships require assessment where airborne contamination presents a credible pathway [6]. Designs address condensate collection, drainage and discharge away from exposed products [7]. Environmental separation remains compatible with cleaning and emergency access.

Design reviews examine zoning drawings alongside material, waste and personnel-flow diagrams [6]. Measurable outputs include barrier locations, door arrangements, access clearances, handwashing provision and any justified pressure or airflow criteria. Construction inspections then verify these outputs against approved documents, while commissioning confirms functional performance under defined conditions before operational acceptance.

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C. Hygienic Materials, Utilities and Equipment Interfaces

Materials are selected for intended food contact, cleaning chemicals, temperature and corrosion exposure, with cleanability considered alongside durability [7]. Joint detailing avoids crevices, exposed voids and inaccessible retention points [7]. Floors require specified gradients, adequate drainage capacity and drain positions compatible with equipment and traffic [6]. Wall-to-floor junctions, coatings and seals must remain intact and accessible for cleaning [10].

Utility requirements distinguish potable water, other process water and systems requiring protection against contamination [5]. Compressed air, steam, refrigeration, ventilation and wastewater provisions reflect their product-contact potential and operational duty [6]. Equipment supports, service penetrations and maintenance clearances require coordinated details rather than separate discipline assumptions [7].

Inspection plans identify material certificates, weld condition, seal continuity, coating integrity, utility connections and interface accessibility. Acceptance criteria precede procurement and installation, specifying the evidence and verification method. Universal gradients, surface finishes or clearance values are inappropriate without process justification [7]. Approved requirements connect design intent with measurable installation acceptance.

D. Regulatory, Standards and Project Documentation Interfaces

Codex establishes HACCP and hygiene principles [4], while ISO 22000 provides requirements for a food safety management system [9]. Applicable hygienic design guidance supports their translation into equipment and facility provisions [7]. Jurisdiction-specific legislation determines mandatory duties; standards remain voluntary unless incorporated through contracts or other applicable obligations [10].

The project compliance register identifies each requirement, source, edition and scope. Design briefs, specifications, drawings and equipment schedules express the resulting engineering provisions. Contractor quality plans identify inspections, hold points and required records. Controlled revisions, named approval authorities and retained evidence preserve accountability. Legal compliance, contractual conformity and operational food safety validation remain related but distinct determinations throughout project delivery and subsequent handover [8].

E. Requirement Traceability Across Project Stages

A requirement register links each identified hazard or prerequisite need to an engineering control, design reference and responsible discipline [4]. Every entry defines review responsibility, verification method, acceptance criterion and evidence location. Changes to layouts, materials or equipment trigger assessment of affected requirements before approval [9].

Nonconformances remain traceable to their source, corrective action and closure evidence. Unresolved risks transfer into construction controls or commissioning restrictions, with named ownership and limits on progression. This proposed arrangement supports documented verification without confusing installation conformity with control-measure validation [11]. The methodology explains how requirements are identified, assigned, reviewed, verified and documented across the lifecycle.

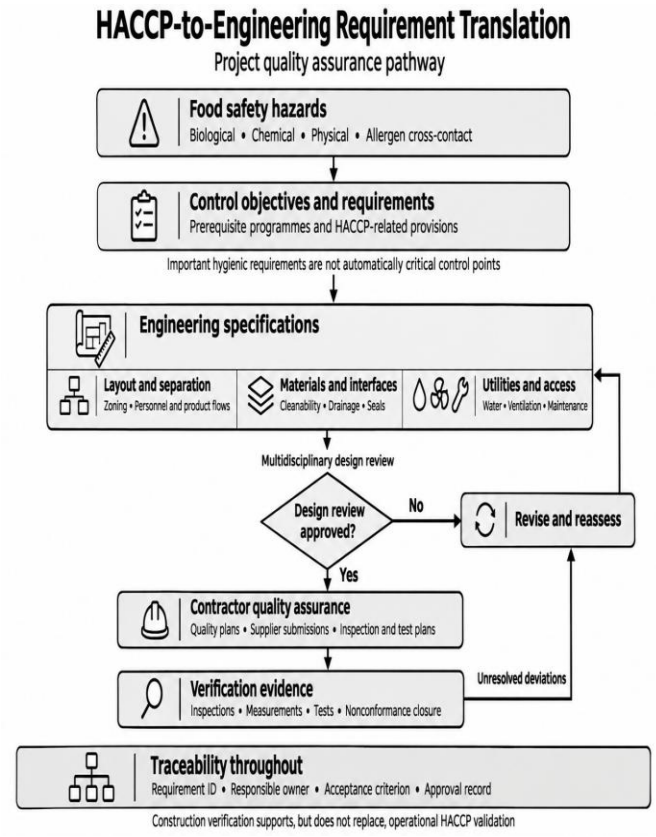


Figure 1. HACCP-to-Engineering Requirement Translation and Project Quality Assurance Pathway.

International Journal of Recent Development in Engineering and Technology
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III. METHODOLOGICAL FRAMEWORK FOR HACCP INTEGRATION

A. Research Design and Framework Development Approach

The study adopts a framework-development approach integrating food safety risk analysis, design assurance and construction quality management. The unit of analysis is an engineering requirement and its verification across project stages, rather than an operational critical control point. Document analysis examines hazard assessments, drawings, specifications, contractor submissions and commissioning records. Requirement mapping identifies connections and omissions, while multidisciplinary protocols and process models define responsibilities, decisions and evidence flows [12].

Evaluation can use expert review, a documented case application or comparison with existing project controls. Each route requires stated selection criteria and evidence limitations. No effectiveness claim follows from framework development alone. Empirical conclusions require actual records or collected evaluation data. The scope covers new facilities and modifications, assuming competent technical input, accessible documentation and project-specific interpretation of applicable requirements [10].

B. Identification and Classification of HACCP-Related Design Requirements

Requirement identification begins with the product, process flow, intended use and environmental hazards. The food safety team identifies facility interfaces supporting prerequisite controls and any infrastructure-dependent operational measures [11]. Requirements are classified under zoning, materials, drainage, ventilation, utilities, equipment installation, cleaning access and environmental control [14]. Each entry records the hazard, control objective, project stage, discipline and expected evidence.

Risk-informed prioritisation considers potential consequence, exposure pathway, detectability and difficulty of later correction. Safety-critical design status indicates project approval significance, not automatic designation as a HACCP critical control point [13]. Requirements become measurable through specified locations, materials, performance limits and test conditions. For example, a drainage objective becomes documented capacity, gradient and discharge criteria justified by the cleaning regime [14]. Acceptance conditions identify methods, tolerances and responsible reviewers before procurement. Ambiguous expectations return for clarification, preventing installation conformity from substituting for an adequate control objective or defensible specification throughout design and construction.

C. Multidisciplinary Design Review Protocol

Checkpoints occur at concept design, detailed design, procurement approval and construction-ready release. Participants include food safety, process, civil, structural, mechanical and electrical specialists, alongside operations and quality assurance. Review questions examine contamination pathways, segregation, drainage, cleaning access, maintenance intervention and utility integrity [14]. Concept review establishes layouts and interfaces; detailed review tests coordinated provisions; procurement review examines supplier proposals; release review confirms approved information.

A register records requirements reviewed, evidence considered, risk classification, decisions and action ownership [12]. Actions receive deadlines and explicit closure evidence. A reviewer other than the action originator verifies closure where independence is required by the project assurance plan. Design changes trigger renewed assessment of affected hazards and interfaces before approval [15]. Unresolved safety-critical matters prevent construction release for the affected work. Authorised reviewers document approval, restrictions and residual risks. This checkpoint arrangement applies project quality principles without representing every review as a separate statutory approval [12].

D. Contractor Quality Assurance Integration

Approved requirements enter contractor quality plans, method statements, material submissions and inspection and test plans. Each inspection identifies the responsible party, timing, acceptance condition and evidence [16]. Hold points prohibit progression without specified release; witness points provide notification and observation opportunities under agreed contractual rules. Plans cover materials, finishes, drainage, utilities, sealing and equipment interfaces, including work concealed by subsequent construction [14].

Contractors submit certificates, photographs, measurements and test results linked to requirement identifiers. Evidence is checked for relevance and completeness, not accepted solely because a form is signed. Deviations enter a nonconformance register with food safety consequence assessment, corrective action and accountable ownership. Competent personnel independent of the corrective work verify closure at the agreed assurance level [17]. Changes affecting hygienic performance escalate to design and food safety leads [15]. Acceptance depends on documented satisfaction or formally justified disposition; schedule pressure

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does not remove applicable requirements or authorise unassessed substitutions [10].

E. Commissioning Verification and Operational Readiness

Commissioning verifies drainage, ventilation, justified pressure relationships, water provision, access and sanitation readiness against approved criteria [14]. Installation checks confirm configuration; functional tests assess performance; cleaning verification examines the defined cleaning outcome. These activities support, but do not replace, operational validation of hazard-control measures [18].

Handover includes approved drawings, inspection reports, certificates, operating instructions, deviations and corrective-action closure [16]. Open risks receive documented assessment, ownership and restrictions before acceptance. Safety-critical unresolved issues prevent unrestricted operation of affected systems. The operational HACCP team uses facility information to finalise process-specific controls, monitoring and validation needs [11]. Readiness therefore represents an authorised decision based on evidence, rather than an automatic consequence of physical completion or the planned construction programme reaching its scheduled end date.

F. Framework Evaluation Criteria and Evidence Collection

Evaluation measures requirement coverage, review-action closure, inspection conformity, nonconformance frequency, rework and commissioning readiness. Each indicator specifies its denominator, reporting period and inclusion rules. Sources include registers, submissions, inspections and commissioning reports [12]. Comparisons use matched phases or a justified baseline, accounting for scope and inspection intensity.

Expert assessment examines usability and completeness, whereas project records assess implementation. Neither independently demonstrates reduced contamination. Documentation quality, project complexity and concurrent management changes limit attribution [19]. Missing evidence remains distinguishable from confirmed failure. These criteria establish the basis for examining application during design development, procurement, construction and project quality assurance without overstating effectiveness.

Table 1. HACCP-Related Engineering Requirement and Verification Matrix.

Food safety hazard or control objective	**Engineering requirement**	**Responsible discipline**	**Design review checkpoint**	**Contractor verification method**	**Acceptance criterion**	**Required evidence**
Cross-contamination between raw and finished products	Risk-based separation of product, personnel and waste routes	Process engineering, architecture and food safety	Concept and detailed design	Layout inspection; barrier and doorway checks	Installed arrangement matches approved zoning and flow requirements; deviations assessed and closed	Approved zoning drawings, flow assessments, inspection records and photographs
Microbial persistence on unsuitable surfaces	Materials and joints suitable for product exposure and cleaning conditions	Architecture, materials engineering and equipment suppliers	Detailed design and procurement	Certificate review; surface, joint, weld and seal inspection	Materials and detailing satisfy approved compatibility, integrity and cleanability specifications	Material submissions, certificates, inspection reports and corrective-action records
Standing water or contaminated drainage	Process-specific gradients, drainage capacity, positioni	Civil engineering and mechanical services	Detailed design and construction-ready	Level survey; installation inspection; functiona	Approved gradients, capacity and drainag	Survey results, test reports, drainage drawings and

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Food safety hazard or control objective	Engineering requirement	Responsible discipline	Design review checkpoint	Contractor verification method	Acceptance criterion	Required evidence
flow	ng and discharge arrangements		release	l drainage tests	e performance achieved under defined test conditions	closure records
Airborne contamination or condensate exposure	Suitable environmental separation, ventilation and condensate management	Mechanical services, process engineering and food safety	Concept, detailed design and procurement	Installation checks; airflow and pressure testing where specified	Approved process-specific environmental criteria achieved; condensate controlled away from exposed product	Ventilation drawings, balancing reports, pressure records and inspection evidence
Contamination through water, air or steam	Utilities appropriate to their intended use and product-contact potential	Mechanical services and utility specialists	Detailed design and procurement	Connection inspection; protective-device checks; specified quality and functional tests	Utility integrity, capacity and quality meet approved requirements	Schematics, certificates, sampling results where required and commissioning reports
Inadequate cleaning or maintenance access	Equipment clearances, supports and service arrangements permit defined tasks	Process engineering, equipment suppliers and maintenance	Detailed design and supplier approval	Dimensional checks; access demonstrations; interface inspection	Specified cleaning and maintenance tasks are achievable using the approved arrangements	Equipment layouts, clearance records, demonstration reports and operating instructions
Contamination through penetrations or concealed defects	Sealed, durable and inspectable service interfaces	Architecture, mechanical and electrical services	Coordinated detailed design and construction release	Inspection before concealment; seal and finish checks	Interfaces conform to approved details, with no unassessed openings or inaccessible defects	Penetration schedules, hold-point releases, photographs and inspection records
Operational release with unresolved hygienic	Evidence-based commissioning and authorised	Commissioning lead, quality assurance, operatio	Commissioning readiness and handover	Dossier review; functional testing; outstanding-action assessme	Required evidence accepted; safety-	Commissioning dossier, risk register, closure evidence

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Food safety hazard or control objective	Engineering requirement	Responsible discipline	Design review checkpoint	Contractor verification method	Acceptance criterion	Required evidence
risks	acceptance	ns and food safety		nt	critical issues closed; other residual risks formally assessed and controlled	and signed acceptance

IV. IMPLEMENTATION THROUGH DESIGN REVIEWS AND CONTRACTOR QUALITY ASSURANCE

A. Embedding Food Safety Requirements into Design Deliverables

The design basis converts hazard-informed objectives into coordinated provisions, with requirement identifiers carried into specifications, drawings and equipment schedules. Process layouts define product and waste routes; architectural details establish barriers and finishes; mechanical and electrical designs address utilities, access and sanitation interfaces. Their coordination matters because individually acceptable components can create unhygienic assemblies.

Formal hygienic review covers zoning plans, drainage layouts, ventilation schematics, equipment arrangements and penetration details. A responsibility matrix identifies who develops, checks and approves each interface, reducing assumptions between disciplines [20]. Conflicts involving cost, access or maintainability receive documented assessment against contamination prevention objectives. Savings do not justify removing necessary controls. Approval requires adequate specifications, coordinated documents and closure of release-critical findings. Controlled issue status then distinguishes information approved for construction from drafts, review copies and superseded revisions, supporting consistent implementation across contractors and supplier packages [21].

B. Risk-Based Design Review and Design Change Control

Risk-based review prioritises requirements according to hazard significance, potential consequence and the likelihood that design or installation fails to deliver the intended control. Review intensity also considers concealment, interface complexity and difficulty of later correction. Findings identify the requirement, affected document, rationale, accountable owner and closure evidence.

Proposed substitutions, value-engineering changes and equipment modifications undergo assessment before approval, including effects on cleaning, segregation, utilities and maintenance access [21]. A cheaper coating, relocated drain or altered support can change hygienic performance despite appearing functionally equivalent. Configuration control preserves the approved baseline and records authorised changes [22]. Revised documents identify affected inspections and commissioning tests.

Unresolved issues escalate to the technical authority, project owner and food safety lead according to consequence. Commercial acceptance cannot replace food safety assessment. Decision records retain rejected alternatives, assumptions and residual risks. Where evidence remains inadequate, the affected procurement or construction release stays restricted until resolution is achieved.

C. Procurement Controls and Supplier Quality Assurance

Procurement packages specify hygienic requirements for food-contact and adjacent materials, finishes, equipment interfaces and utility components. Supplier drawings, datasheets, certificates and installation instructions are assessed against the approved design basis rather than accepted as independent proof of suitability [21]. Qualification considers relevant capability, traceability and evidence from comparable supplies.

Factory acceptance testing applies where predefined functions or interfaces can be verified before delivery. It does not replace site checks of installed configuration or utility performance. Proposed material substitutions require documented comparison of compatibility, cleanability, durability and interface effects [22]. Acceptance identifies limitations and any additional verification.

Approved supplier information feeds installation methods and inspection plans, preventing procurement decisions from

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bypassing design requirements [20]. Early review can reduce avoidable defects, but effectiveness requires recorded outcomes rather than assuming fewer nonconformances follow automatically.

D. Construction Inspection, Testing and Nonconformance Management

Inspection and test plans convert approved requirements into scheduled site checks, with defined methods, inspectors, frequencies and release conditions [20]. Checks cover floor slopes, drainage connections, coating continuity, weld quality, penetrations, sealing and equipment clearances. Visual inspection identifies defects; dimensional measurement verifies geometry; functional testing assesses performance; specialist assessment examines hygienic suitability where ordinary inspection is insufficient.

Evidence includes traceable measurements, calibrated instrument details, photographs and signed inspection records. Hold points apply before concealment or irreversible work, with release by the authorised person [20]. Witness arrangements identify notification requirements and consequences of nonattendance.

Nonconformances enter a risk-informed process covering detection, classification, containment, correction, reinspection and closure [21]. Food safety consequences determine escalation and restrictions, while closure requires evidence rather than assurances. Repeated defects trigger investigation of underlying causes, such as inadequate detailing, unsuitable methods or misunderstood specifications [17]. Corrective action addresses recurrence, with effectiveness checked in subsequent work. Unresolved deviations transfer into commissioning decisions and prevent unrestricted acceptance where hygienic performance remains unproven or necessary controls are compromised by incomplete corrective work.

E. Integrated Review and Quality Assurance Workflow

The integrated sequence begins with hazard identification and approved engineering requirements, followed by design verification, procurement review, construction inspection and commissioning acceptance. Registers, coordinated drawings, supplier approvals and inspection releases connect successive gates. Quality plans define evidence needed before progression [20]. The project owner assigns authority, resources and escalation routes; the food safety team checks whether provisions support the intended control objectives.

Design and contractor teams exchange findings through a common requirement identifier. A supplier deviation returns to technical review, while a construction nonconformance prompts correction and, where necessary, design reassessment. Configuration records preserve the resulting approved arrangement [22]. Commissioning tests use that arrangement, not an obsolete specification.

Traceability reduces the opportunity for requirements to disappear during package transfers or handover, but its effectiveness requires evaluation [19]. Acceptance confirms evidence completeness and technical satisfaction, retaining restrictions on unresolved release-critical issues.

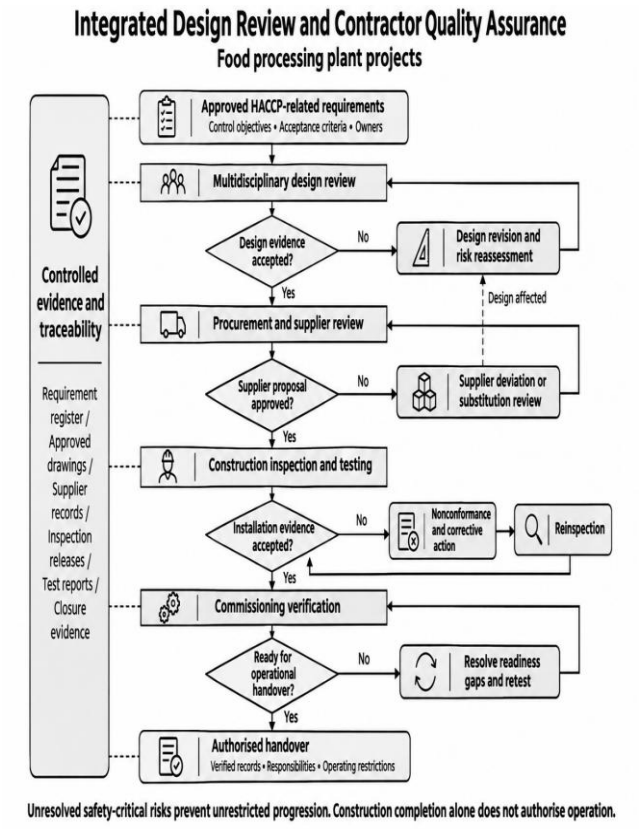


Figure 2. Integrated Design Review and Contractor Quality Assurance Workflow for Food Processing Plant Projects.

F. Documentation, Accountability and Handover Control

A controlled repository retains design approvals, review findings, inspection results and commissioning evidence. Digital registers link requirement identifiers with current documents, decisions and closure status, supporting information coordination without

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equating software adoption with assurance [23]. Access rights, revision histories and retention rules protect record integrity.

Requirement owners maintain technical intent; authorised specialists accept discipline evidence; designated reviewers verify nonconformance closure; the owner approves handover with food safety input. The minimum package includes as-built drawings, certificates, test reports, manuals, maintenance requirements and an outstanding-action register [20]. Records support later modifications, maintenance and inspection by showing what was approved and verified [24]. The next section evaluates effectiveness, trade-offs and organisational conditions, recognising that documentation alone does not demonstrate hygienic performance or safe operation.

V. FRAMEWORK EVALUATION, DISCUSSION AND PRACTICAL IMPLICATIONS

A. Evaluation of HACCP Requirement Coverage and Design Review Effectiveness

Requirement coverage is the proportion of applicable engineering requirements supported by documented design verification. The denominator excludes requirements formally judged inapplicable, while additions and revisions remain visible. Coverage measures evidence presence, not automatically its adequacy. Review therefore checks whether documents address the intended control objective and whether competent reviewers accepted the evidence [25].

Closure rates distinguish findings resolved within their required stage from overdue, deferred and reopened items. Repeated observations identify ineffective correction or unclear specifications. Assessment also records when issues first emerge: concept review, detailed design, procurement, construction or commissioning. Detection counts require interpretation against review effort and scope.

High-risk unresolved requirements receive separate reporting rather than disappearing within an overall percentage. Project complexity, process hazards and package boundaries influence comparison. Numerical coverage, closure and timing results are reported only from actual registers; without those records, this section establishes evaluation criteria rather than claiming demonstrated design review effectiveness across projects.

B. Contractor Quality Assurance Performance and Construction Compliance

Construction evaluation links each approved hygienic requirement to its required inspections, completed checks and acceptance evidence. Indicators include inspection completion, first-pass acceptance, nonconformances per inspected work unit, closure time and recurrence. Denominators and severity categories remain explicit so unlike activities are not combined into misleading totals [26].

Administrative completion does not establish hygienic suitability. A signed checklist may confirm inspection occurred without demonstrating adequate cleaning access, drainage or interface integrity. Evidence review therefore examines measurements, test conditions and competent acceptance against approved criteria.

Assessment records whether controls identify defects before concealment, commissioning or operational release. Subcontractor competence, inspector availability and documentation quality affect both detection and reporting. Higher recorded defects can indicate stronger surveillance rather than poorer workmanship. Conversely, low counts can reflect insufficient inspection. Interpretation therefore combines severity, exposure, recurrence and detection timing rather than ranking contractors by defect counts alone. Independent sampling compares recorded compliance with installed conditions.

C. Rework Prevention, Project Efficiency and Food Safety Readiness

Early reviews identify design conflicts promptly. Potential benefits include fewer modifications, clearer installation sequencing and reduced disagreement over acceptance. These are mechanisms, not measured savings. Evaluation requires records linking identified issues, corrective decisions, avoided or incurred work and associated programme effects [27].

Rework assessment distinguishes design omissions, supplier deviations, workmanship defects and client changes. Costs include labour, materials, disposal, retesting and disruption, with transparent allocation rules. Comparisons also account for additional review hours, specialist inspection and procurement restrictions. Integration can increase upfront effort even where it reduces later uncertainty [28].

Traceability supports readiness by connecting the installed configuration with outstanding actions, maintenance needs and operational controls. It also assists subsequent modifications, where original assumptions require reassessment. Nevertheless, documentation completeness does not independently demonstrate effective sanitation or safe product disposition. Claims of reduced contamination or illness require operational monitoring and evaluation beyond construction records or improved commissioning documentation alone [32].

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D. Comparative Assessment of Conventional and Integrated Project Quality Practices

The conceptual comparison contrasts disconnected approvals with a linked requirement pathway, rather than assuming conventional projects lack food safety controls. Some existing arrangements already involve competent food safety reviewers, coordinated specifications and effective inspection planning. Where those practices provide equivalent coverage, additional registers or meetings may duplicate work without improving decisions [28].

Integration adds value when responsibility, evidence or escalation becomes unclear between disciplines and contractual packages. Food safety participation moves upstream, while contractors retain installation responsibilities and operational teams retain process-specific validation duties. Requirement identifiers connect review findings with procurement, inspection and readiness evidence [24]. This supports shared verification rather than transferring accountability to one specialist.

Table 2 summarises expected differences and trade-offs. It remains a proposed comparison until matched project evidence establishes whether the integrated approach changes outcomes.

Table 2. Comparative Assessment of Conventional and HACCP-Integrated Design Review and Contractor Quality Assurance Practices.

Evaluation dimension	Conventional project practice	Proposed HACCP-integrated practice	Verification indicator	Expected benefit or trade-off
Food safety participation	Participation may occur through separate technical or late-stage reviews	Food safety input at defined design, procurement and readiness gates	Reviews involving designated food safety personnel	Earlier consideration of hazards; additional specialist time
Requirement coverage	Requirements distributed across discipline documents	Applicable requirements mapped to design references, owners and evidence	Proportion with documented design verification	Better visibility of omissions; register-maintenance effort
Design coordination	Interfaces managed through discipline coordination procedures	Hygienic interfaces explicitly included in coordinated review	Unresolved interface findings at construction release	Fewer unassessed gaps; possible duplication where controls already work
Procurement	Supplier approval emphasises technical and contractual conformity	Hygienic requirements included in submissions and substitution assessments	Approved substitutions with documented food safety review	Earlier detection of unsuitable proposals; potential procurement constraints
Construction inspection	Checks follow drawings, specifications and established quality plans	Checks trace directly to approved hygienic requirements	Completed inspections supported by adequate acceptance evidence	Clearer control objectives; more detailed inspection planning
Nonconformance escalation	Deviations managed through contractual and technical processes	Food safety consequences determine escalation and progression restrictions	Severity, closure time, recurrence and closure verification	Risk-sensitive decisions; specialist review demand
Rework	Modifications recorded through existing cost and change	Rework linked to requirement origin and detection	Rework cost and timing by documente	Better learning; additional coding and attribution

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Evaluation dimension	Conventional project practice	Proposed HACCP-integrated practice	Verification indicator	Expected benefit or trade-off
	systems	stage	d cause	effort
Commissioning readiness	Completion and outstanding-work lists support release	Functional evidence and unresolved hygienic risks inform acceptance	Release-critical actions closed or formally restricted	Clearer readiness decisions; possible delayed release where evidence is incomplete
Handover and future changes	Records transferred through established document systems	Requirement, configuration and verification records remain linked	Traceable records available to operations and food safety teams	Better continuity; continuing ownership and updating obligations

E. Implementation Challenges, Limitations and Transferability

Implementation depends on access to food safety expertise, coordinated contracts and documentation. Schedule pressure can encourage premature release, while broad requirements such as cleanability remain difficult to inspect without agreed methods. Explicit criteria help, but cannot eliminate professional judgement or substitute for competent assessment [30].

Requirements differ across dairy, meat, beverages and ready-to-eat processing. Wet cleaning, exposed products, allergens and environmental separation create different control priorities. Adaptation therefore considers process risk, facility scale, jurisdiction and delivery method rather than applying a universal checklist.

Expert review can assess plausibility and usability but is vulnerable to participant selection and shared assumptions. A single project offers contextual detail without demonstrating wider effectiveness [29]. Incomplete follow-up limits assessment of sustained hygienic performance. Missing records, changing inspection intensity and concurrent management improvements complicate attribution. Comparative evidence remains necessary before generalising benefits across sectors or organisations.

F. Implications for Engineering Practice and Future Research

Engineering practice benefits from involving food safety specialists before layouts and procurement decisions become fixed. Requirement-based checklists, inspection plans and explicit acceptance authorities provide practical starting points. Digital registers and BIM-supported coordination can connect requirements with locations, interfaces and evidence, but software does not establish technical adequacy [23]. Information responsibilities and controlled revisions remain essential [31].

Research priorities include multi-project evaluation, comparable risk and scope definitions, and transparent assessment of implementation effort. Studies should quantify rework, detection timing, commissioning restrictions and readiness decisions, then examine operational cleaning and environmental outcomes where appropriate [32]. Longitudinal assessment can identify whether benefits persist after handover. These findings can refine review intensity, acceptance criteria and governance, supporting wider adoption only where evidence demonstrates value. The conclusion consolidates the contribution, implementation conditions and validation boundaries.

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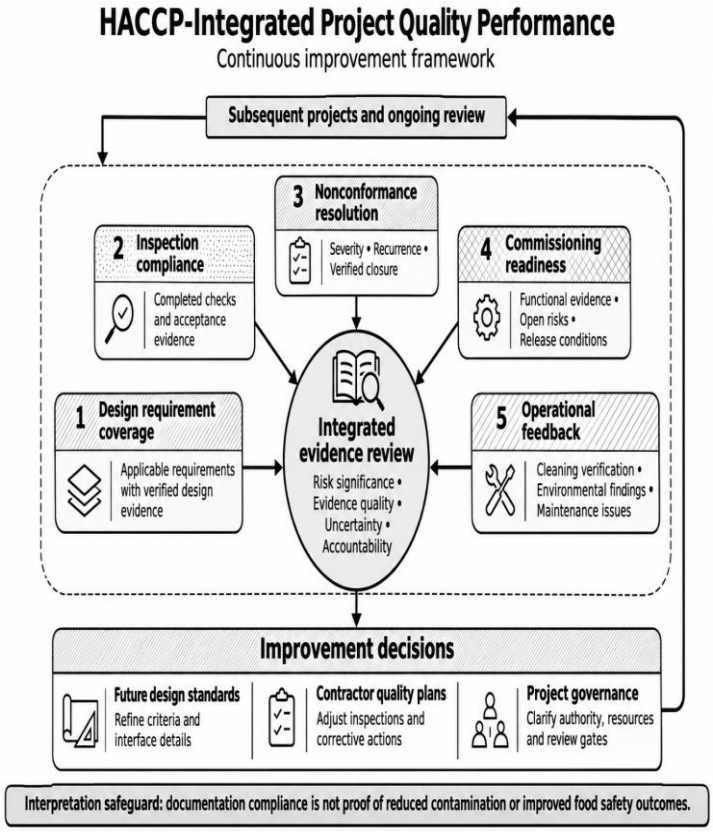


Figure 3. HACCP-Integrated Project Quality Performance and Continuous Improvement Framework.

VI. CONCLUSION

A. Integrated Contribution and Principal Findings

Aligning HACCP-related requirements with engineering delivery requires more than separate food safety assessments and construction inspections. The proposed framework connects identified hazards and control objectives with measurable specifications, multidisciplinary design reviews, contractor verification and commissioning decisions. Requirement traceability preserves the relationship between design intent, installed provisions and acceptance evidence, while defined responsibilities support escalation and closure of nonconformances.

Its contribution is conceptual and procedural: it provides an integrated method for organising project assurance, rather than demonstrated reductions in defects, contamination or expenditure. Earlier identification of hygienic deficiencies may prevent avoidable modifications, but that benefit requires project evidence. Systematic nonconformance management similarly supports accountable decisions without guaranteeing effective correction. Facility hygienic design and operational HACCP validation therefore remain connected but distinct responsibilities. Construction acceptance confirms specified provisions and performance; operational teams still establish and validate process-specific controls using evidence before production.

B. Conditions for Effective Industrial Implementation

Effective implementation depends on competent participation across food safety, engineering, procurement, construction and operations. Approved specifications require objective acceptance criteria, while contractors need clear accountability for installation and evidence. Formal review gates, controlled changes and complete inspection records support decisions before work becomes concealed or irreversible.

Procurement coordination prevents substitutions from bypassing hygienic requirements. Independent verification applies where justified by risk and the assurance plan, and structured handover transfers drawings, tests, maintenance information and outstanding-action responsibilities. The framework requires adaptation to applicable food hygiene regulations, process hazards and facility conditions. Management commitment must provide resources, authority and time for review and correction. Operational ownership maintains the connection between verified infrastructure, sanitation arrangements and continuing food safety responsibilities after project completion.

C. Future Research and Concluding Perspective

Future research should evaluate the framework across processing sectors, facility scales and delivery arrangements. Comparative studies can quantify requirement compliance, defect detection, rework, commissioning delays and readiness, accounting for inspection intensity and project complexity. Digital quality systems and BIM-supported verification warrant assessment for traceability, usability and maintenance burden.

Systematic integration can strengthen the basis for contamination prevention, construction accountability and hygienically suitable facilities when supported by competent judgement and verified evidence. Wider adoption should follow demonstrated value, with operational follow-up establishing whether project controls continue to support food safety management.

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